prior to the beginning of selective killing, to 35 pounds per acre in 1957. The 1958 poundage was virtually unchanged from that of 1957.

TABLE II

SUMMARY OF FISH RECOVERED IN ROTENONE SAMPLINGS OF HERRINGTON LAKE FROM 1955 THROUGH 1958

Year	Lbs. Per Acre of Game Fish	Lbs. Per Acre of Panfish	Lbs. Per Acre of Rough Fish	Lbs. Per Acre of Forage Fish*	Total Lbs. Per Acre
1955	41	18	37	282	378
1956	38	16	31	122	198
1957	52	8	15	35	110
1958	26	6	27	43	100

* Over 95 percent of the weight of this group was gizzard shad.

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RESERVOIR OPERATION FOR STATUTORY PURPOSES

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ABSTRACT

The Corps of Engineers of the Department of the Army plans and constructs authorized flood control and multiple-purpose reservoirs under the general provisions of the Flood Control Acts of 1936 and 1944 and other legislation authorizing specific reservoir projects. The 1944 Act delegates to the Secretary of the Army responsibility for prescribing regulations for the use of flood control or navigation storage at all reservoirs, except those of the TVA, constructed wholly or in part with Federal funds.

Effective functional operation of reservoirs is a most important factor in insuring that they accomplish the purposes for which they were designed and produce the benefits which justified their construction. Flood control, navigation, and power development, singly or in combination, are the major purposes for which reservoir projects have usually been authorized in Southeastern United States. Where uses of reservoir sites for agriculture, forestry, fish and wildlife conservation, and recreation were not inconsistent with the project operation for its authorized purposes, they were developed as an active part of the project.

The management of the fishery resource of a Federal reservoir is recognized as the responsibility of the state(s) in which the project is located. The Corps of Engineers cooperates with states to the extent possible in operating water levels for fishery benefits. Water-level management on reservoirs operated primarily for flood control is generally compatible with fish-management programs. Regulation schedules on multiple-purpose reservoirs are not subject to drastic

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changes for fishery purposes, but minor seasonal modifications are sometimes possible. Abnormal water levels during floods or droughts offer other opportunities for executing desirable fish management practices. Fishery personnel are urged to consider fully in their management plans the physical, operational, and economical limitations of individual reservoirs.

INTRODUCTION

The fact that flood control and navigation are the responsibility of the Corps of Engineers appears to be generally known and accepted. Furthermore, it is generally recognized that flood control, navigation, and power development, singly or in combination, are the major purposes for which reservoir projects have usually been authorized and constructed in the Southeastern United States. On the other hand there, at times, seems to be a misunderstanding or an unawareness among fish and wildlife interests, with respect to the origin of such projects and the statutory, as well as the physical and economic limitations which must be considered in developing and operating such projects.

In recent years the more than 130 existing Corps of Engineers' reservoirs in this country have assumed great importance in connection with outdoor recreation (of which fishing plays a major part). Their use in this regard should continue to increase as time goes on. In order to plan and carry out effective reservoir fish management programs, every administrator of those resources, as well as the research and management biologists in the field, should have a general knowledge of the various factors which must be considered in regulating a reservoir.

AUTHORITY FOR RESERVOIR DEVELOPMENT AND OPERATION

The Corps of Engineers of the Department of the Army plans and constructs authorized flood control and multiple-purpose reservoirs under the general provisions of the Flood Control Acts of 1936 and 1944 and other legislation authorizing specific reservoir projects. The 1944 Act delegates to the Secretary of the Army the responsibility for prescribing regulations for the use of storage allocated for flood control or navigation at all reservoirs, except those of the TVA, constructed wholly or in part with Federal funds. Other laws have been enacted by Congress to expand the Federal interest and activity in water resource development to include, in varying degrees, hydroelectric power, navigation, water supply, recreational use, and consideration of fish and wildlife preservation and enhancement.

Before any project is studied by the Corps of Engineers, Congress passes a resolution which indicates the area which should be considered and the primary purposes of the proposed water development project. Then a survey report is prepared to determine if a plan of improvement can be developed which is economically feasible. The function of the Corps of Engineers in this connection is to determine, on the basis of sound engineering and economic criteria, whether a project should be built or a plan of development undertaken, so that Congress may have a firm basis for action when authorization bills are being considered. The Corps is the consulting Engineer for Congress and the people.

OBJECTIVES OF RESERVOIR OPERATION AND REGULATION

Effective functional operation of reservoirs is of utmost importance in insuring that the reservoirs are regulated to accomplish the purposes for which they were designed and that they produce the maximum possible benefits, consistent with their physical characteristics. The objectives of reservoir regulation are to reduce flood damages to the greatest extent possible with available facilities and to provide maximum beneficial use of available storage for other project purposes. In developing an operating plan, detailed studies should be made to determine the effect of various regulation schedules on the floods of record, hypothetical floods, and on benefits obtained from other authorized purposes. Where a project has been adequately designed on the basis of an acceptable operating plan, it is inadvisable to make drastic changes in the regulation schedule without a comprehensive investigation of the probable results.

METHODS OF RESERVOIR OPERATION

The method of operation of a reservoir is the most important factor in insuring the realization of the benefits which justified construction of the project. The best method of attaining the objectives of flood control is often difficult to determine. It depends principally on the location and type of damage to be prevented, location and amount of storage capacity, flood characteristics, flood frequencies, and extent of the uncontrolled drainage area. However, the general plan of operation finally adopted usually can be identified with one of the three following methods:

A. *Regulation based on maximum beneficial use of the available storage during each flood event.*—This method is based on the concept of reducing damaging stages at the locations being protected as much as possible during each flood with the currently available storage space. As an example, if there were three inches of flood-control capacity available at the beginning of a flood, the reservoir would be operated so as to use all of that capacity in reducing the damages downstream based on the predicted runoff for that particular flood. Thus the possibility of having the storage capacity filled upon the unexpected occurrence of a large subsequent flood is largely disregarded. By making full use of reports from an adequate network of hydrologic stations and proper evaluation of the immediate weather forecast and seasonal probabilities, the calculated risk is reduced to a minimum, however. This type of regulation is useful in cases where the available flood control storage is insufficient to control the larger floods occurring less frequently than once in 10 or 15 years.

B. *Regulation based on control of project design flood.*—This is the usual project where flood control capacity is sufficient to control the project design flood. The operation consists of releasing an established amount and storing all excess inflow as long as flooding continues. As a project design flood represents an unusual event, a fixed schedule of regulation which makes full provision for its occurrence affords considerable assurance of satisfactory regulation of all large floods. The extent of the downstream benefits that can be provided by this method of regulation is dependent on the amount or volume of flood control storage that can be economically provided.

C. *Combination of methods A and B.*—A combination of the two methods often results in the best apparent overall regulation. For example, in protecting agricultural areas, a regulation plan for maximum damage reduction during ordinary floods may be desirable during the main growing season but may not be the most advantageous plan during the winter or spring flood season. It may also be desirable to provide reserve storage to give increased insurance of protection for a leveed town or industrial area which is endangered only by unusual floods. Thus, after the lower part of the storage is filled, a fixed schedule of releases would be followed to assure greater control of major floods.

REGULATION SCHEDULES FOR VARIOUS TYPES OF RESERVOIRS

Single-purpose reservoir.—In the case of a single reservoir built for the protection of the local area immediately downstream from the dam, the regulation schedule generally consists of passing all inflow up to the carrying capacity of the channel and is the same for all methods discussed above.

If benefits are to be obtained at some downstream city or development rather remote from the dam, regulation under method A would consist of keeping the river flow at that location within bankful capacity. If that is not possible because of contributions of flow from uncontrolled portions of the drainage basin, regulation at the dam should be such as to provide no discharge or a minimum contribution to the already bankful condition. Releases at the dam would be based on observed or forecast runoff conditions at key locations in the uncontrolled drainage area. Regulation schedules for method B would provide for releasing water at rates so that the design flood could be controlled without exceeding the flood control storage capacity allocated in the reservoir.

Where primary reservoir regulation benefits are sought at both local and remote locations below the dam, the method of regulation and preparation of schedules becomes more complicated than if remote area benefits alone are involved. That is because additional restrictions placed on releases from the

reservoir require a larger storage capacity. It is obvious that the beneficial effects of a reservoir in preventing flooding decrease progressively downstream. Beyond a reasonable distance the benefits may be so reduced that no method of regulation would produce significant benefits.

Multiple reservoir system.—In the development of regulation schedules for an integrated system of reservoirs, general schedules are first developed for the tributary reservoirs operating as separate units. The adjustment of the individual regulation schedules for coordinated operation of the various tributary and main river projects must be based on analyses of the basin project plan and design floods. The critical basin flood may be a succession of moderate floods rather than one severe flood, depending on channel capacities and the method of regulation adopted. If channel capacities below the individual dams are limited and both remote and local benefits are to be obtained at scattered locations, it is quite possible that sufficient storage would not be available for complete control of a critical basin-wide flood. Therefore, regulation based on maximum use of available storage (Method A) would probably provide the maximum benefits for the system. If channel capacities below the dams are large and the remote benefits are to be obtained at a few centralized locations, successful operation based on the control of design floods at the individual reservoirs (method B) is possible. Regulation schedules for a multiple-reservoir system are based on making fixed or variable releases depending on existing or forecast stages at certain control points. Therefore, it can normally be expected that a combination of methods A and B would provide the most dependable benefits.

Multiple-purpose reservoirs.—An increasing number of multiple-purpose reservoirs are being planned and built, particularly in connection with basin-wide development of natural resources. In some instances, joint reservoir storage is provided for low-water regulation, navigation, irrigation, water supply, sanitation, power-production, recreation, and other purposes. These purposes may be served by allocating capacity between particular levels for specific purposes in addition to that required for flood control. Regulation for flood control is similar to that for a single-purpose reservoir, and operation for the other functions ordinarily follows rule curves of elevation or storage capacities plotted against the time of year. The rule curves and allowable release rates are developed from a study of the stream-flow record for the period most critical with respect to the desired operation.

Sufficient storage capacity often is not available to fully provide for all the desired functions in a multiple-purpose reservoir. For projects where economic or physical considerations prevent the provision of adequate storage capacity for all of the desired purposes, use of the same space is attempted for flood control and for other purposes on a use schedule that varies with the different seasons of the year. Successful operation of such projects requires climatic conditions such that major floods would occur in only one or two seasons of the year and that the runoff characteristics are such that the conservation storage space could be filled during the latter part of the major flood control period.

Seasonal variation of storage allocation.—In the normal case, where seasonal use of storage is possible, a certain minimum capacity is allocated to the several uses. This is supplemented whenever possible during other seasons. The amounts and variation in allotted capacities are based on analyses of benefits, costs of required construction, types of areas being protected from floods, and past hydrologic records and consideration of regional hydrologic characteristics. The rule or guide curve for the conservation phase will indicate elevations which may not be exceeded at any particular time except for the purpose of storing floodwaters. Regulations generally require that storage for flood control above the conservation pool be emptied in a reasonably short period of time after the necessity for flood control storage has ended. Zones are designated within the conservation pool allocation, and criteria are established to govern the release of stored water for power production or low-water regulation.

Regulation within the power pool.—Reservoir regulation for power production within the range of the power pool is usually designed to minimize the waste of water. This normally results in a seasonal filling and withdrawal of storage (Figure No. 1). Such operations may result in incidental flood control and fish

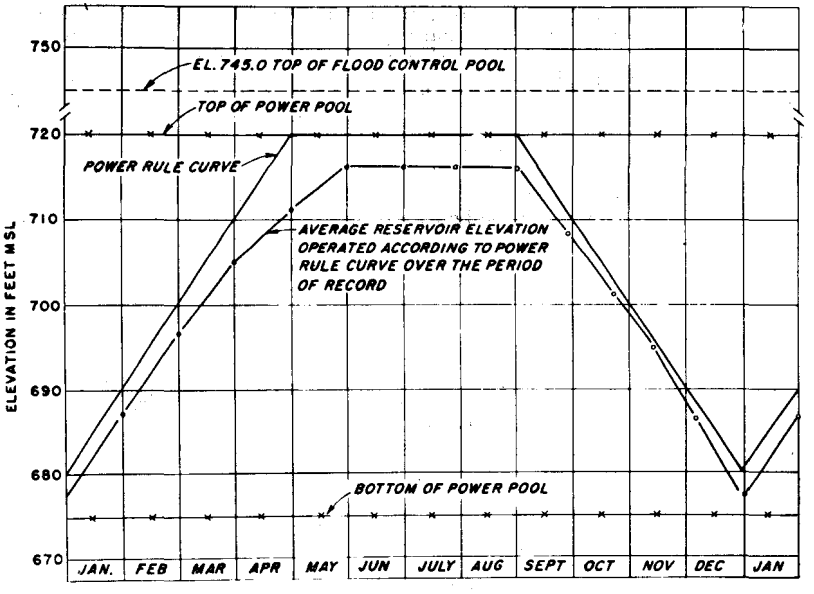

FIGURE 1 SEASONAL REGULATION CHART

and wildlife benefits. A guide curve of annual variations of the power pool level is developed to coincide with the lower limit of annual variation of the reservoir level so that only primary energy is generated when the reservoir level falls below the curve. Thus, there would be no time when primary energy could not be produced. In the case of projects with constant storage allocations, secondary energy is developed with the excess water available whenever the reservoir level is above the guide curve. Greater incidental flood-control benefits would also be provided by the release of water stored above the elevation indicated by the rule curve and below the top of the power pool at certain times as the result of secondary discharges for power generation or by purposely discharging unneeded waters. For projects with seasonal variation of storage allocations, it is often desirable to establish an intermediate zone between the storage reserved exclusively for flood control and that required to develop primary power requirements. This would be done to assure the availability of flood control storage when needed and to still allow for power to be developed from water stored during minor rises. Operation within that intermediate zone would require evacuation within a fixed period or power production at 100 percent load factor, or a combination of both. Operation above that zone would require full flood-control releases. Considerations other than power generation or release of excess storage may require some modification of the lower and upper guide curves, particularly if the project is one unit in a system.

During flood periods, release through the power plant may be restricted, because of downstream conditions, to as little as zero in extreme cases and otherwise to the average daily release required to generate the primary energy of the project in accordance with the system demands and the capacity of the plant. In power production abnormal operations of the reservoir in the interest of flood control may be compensated for by maximum use of other plants feeding into the same transmission system located outside the zone of flooding.

OPERATION OF SPILLWAYS

General.—The effects of large deep reservoirs on the natural discharge of rivers are shown by developing "inflow to full pool" hydrographs, as well as hydrographs for corresponding design floods under natural conditions. An earlier and higher peak on the inflow to full pool graph results primarily from the

increased water depth and decreased friction in the flooded or reservoir pool sections of the main river and tributary systems above the dam. The flow from the upper basin reaches the dam earlier than would occur under natural conditions and may synchronize to a greater extent with the inflows from the local areas and lower tributaries discharging directly into the reservoir pool. A secondary effect results from the fact that the dampening effect of valley storage within the reservoir pool is less under artificial conditions of flow through reservoirs than under natural river conditions.

Gated spillways.—Insofar as practicable, Corps of Engineers' reservoirs controlled by gated spillways are designed and operated to accomplish the following objectives when the reservoir is filled or nearly filled.

(1) Peak rates of release during damaging floods should not exceed peak rates of corresponding floods that would have occurred under runoff conditions prevailing before construction of the reservoir.

(2) The rate of increase in reservoir releases during a significant increment of time should be limited to that which would not constitute a major hazard to downstream interests. When predictions indicate that expected runoff will appreciably exceed the storage capacity remaining in the reservoir, the opening of the spillway gates is initiated before the reservoir has filled and is scheduled to limit the rate of increase in outflow to an acceptable value. Because of their rare frequency of occurrence, many technical aspects of spillway operation, such as induced surcharge storage, are probably of little significance in fishery management programs.

The above discussion has merely touched the high spots of reservoir operation and is a very brief outline of the main considerations of regulating the various pool levels and releases for project purposes. Much more detailed information is available for those who desire it for planning fish management programs within the limits of operations scheduled for the conservation pool and of the pools provided primarily for other purposes. The following reports are usually available, for examination at least, in the District offices, and, probably at the offices of the individual reservoir managers.

1. *The Definite Project Report or General Design Memorandum* in which the plan of regulation and the general operating procedure are developed.

2. *Manual of Reservoir Regulation* contains description of drainage basin and information pertinent to operation of the project.

3. *Monthly Report of Reservoir Regulation.*—Monthly data charts which show water surface elevations, storage and pool elevations, guide curves, power releases, total releases, precipitation, total and peak inflows, and other pertinent information (Figure No. 2).

LIMITATIONS OF OPERATION FOR FISH AND WILDLIFE PURPOSES

General.—Where do fish and wildlife and recreation fit into the above picture of reservoir operation? For many years it has been a part of project planning by the Corps of Engineers that when uses such as agriculture, forestry, fish and wildlife conservation, and recreation are not inconsistent with the project operation for its authorized purposes, they be developed as an active part of the project. Many fish and wildlife refuges, game management areas, and fishery facilities have been developed in connection with Federal reservoir projects. The Corps of Engineers also plans for the development of needed access points, launching ramps and landings, roads and parking areas, and other basic public recreational facilities at each of its projects. Those facilities are developed as funds are made available for those purposes. Summarizing it another way, it can be stated that on Corps of Engineers' projects fish and wildlife interests will be protected or provided for, to the fullest extent, consistent with paramount project objectives, availability of funds, and governing laws and regulations. An examination of the various limitations in those respects will give some idea of what the Corps of Engineers can and cannot do in connection with reservoir operation for fish and wildlife benefit.

Statutory limitations.—In the Congressional authorization of specific reservoir projects, it is generally stated for what purposes the project will be built and

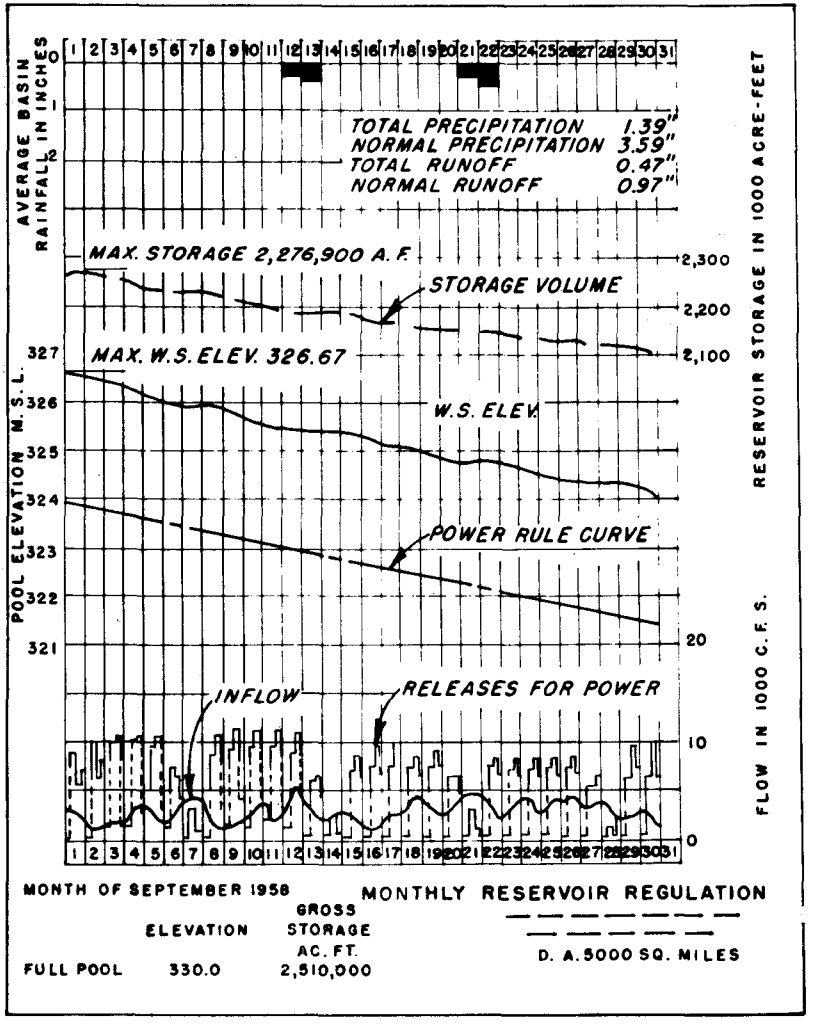

FIGURE NO. 2 TYPICAL MONTHLY RESERVOIR REGULATION CHART

operated. On most of the existing projects, Congress did not recognize fish and wildlife as a primary purpose. Previously, without proper authorization being included, the Corps has had no means of accomplishing desirable conservation improvements, other than those that occurred incidentally.

In the preceding discussion, some of the many problems connected with the regulation of water levels for the authorized purposes were outlined. Standing out among those considerations is the fact that a full reservoir does not provide flood control. There is never any assurance that a major flood will not occur immediately following a series of small ones which have filled the storage pool. Therefore, the flood control storage pool must be emptied generally as soon as downstream conditions permit, even though the maintenance of the higher pool might provide a better fishery situation. Furthermore, primary operation for

power production or water supply requires a minimum waste of water within those pools. Thus, the permissible releases have, of necessity, often been limited to those which will preserve the downstream fishery rather than those which will enhance it. Therefore, to assure additional works needed to enhance the fishery resources, fish and wildlife needs to be authorized as a primary project purpose. The revised Coordination Act of 1958 (PL 85-624) will provide increased opportunity in that respect. However, it would appear that fish and wildlife interests must still convince local people and Congress of the benefits to be derived from such consideration and be prepared to justify their recommendations with facts and figures in preauthorization reports so that Congress will have sufficient information for consideration of whether or not fish and wildlife warrants a primary purpose, along with flood control, navigation, and other major purposes.

Physical limitations.—Some reservoirs are physically limited so that sufficient storage capacity is not available for all desired purposes. In such cases, the same storage space is used for different purposes at different seasons of the year. Some functions must be given secondary consideration when regulation schedules are being developed for a specific purpose. The operation of the reservoir must also coincide with the seasonal rainfall pattern. It is not possible, for example, to provide and maintain a high pool in the fall every year for fishery benefits, if the main rainy season occurs in the spring. This or higher water levels in other seasons is a frequent request of wildlife and fishery interests. The physical characteristics of a reservoir, including depth, size, type of watershed, turbidity, and many other factors may limit its potentialities for producing the desired species of fish or otherwise contribute to unsatisfactory fishing conditions. Such undesirable physical conditions are not easily controlled and are seldom eliminated, especially on reservoirs which have been constructed for purposes other than for the enhancement of fishing.

Economic limitations.—The total costs of a reservoir project are generally allocated proportionately among the various purposes for which the project was authorized and which receive benefits. The operation of the project so as to store or use the available water for incidental benefits, cannot be accomplished at the expense of a primary benefit, which was used in justifying the costs. Wiebe (1957) cites one example at a TVA reservoir where a request by a cooperating agency for water would have sacrificed annually power energy worth $362,000 in order to save an expenditure of $5,000. In general, the high fish and wildlife and recreation benefits produced at existing reservoir projects have occurred incidental to development for other purposes, and the costs of the dams and their operation has been justified by those other functions. The recreational resources, while large and important, have been produced as by-products of projects justified for other purposes. In the past, the large expenditures for recreation which can be associated with individual projects have not been applied to a share of the cost of the dam which made those recreation resources available. In future projects where recreation or fish and wildlife may be considered a primary project purpose, some decision must be made for assigning a share of the costs for that purpose between Federal and non-Federal interests. In any case, if fish and wildlife interests desire to have added benefits, in addition to those they now receive incidentally on projects built for flood control, power, and navigation, they should be prepared to bear a proportionate share of the cost.

Irrespective of whether existing or future projects are being considered, it is urged that the physical, economic, and statutory limitations of any reservoir used for fishery purposes be recognized in program development by those charged with the management of its fishery resources. There is little purpose in attempting to set up management procedures which call for drastic or undesirable changes in authorized operations.

OPPORTUNITIES FOR RESERVOIR OPERATION FOR FISH AND WILDLIFE PURPOSES

The management of the fishery resources of a Federal reservoir has long been recognized as the responsibility of the state(s) in which the project is located (Thompson, 1955). The Corps of Engineers to the extent possible cooperates

with states in operating reservoir water levels and providing assistance with management for fishery benefits. Examples of such cooperation are: attempts to control carp in at least two states, Georgia and South Dakota, where variations in water levels were requested; assistance with personnel and equipment in the collection of creel census and population data on numerous reservoirs throughout the country; and participation in Oklahoma (Thompson, 1955), and more recently in South Carolina and Georgia, in cooperative councils of State and Federal agencies concerned with reservoir fishery management.

Water level management on reservoirs operated primarily for flood control appears to be generally compatible with present programs for fish management, particularly from the standpoint of population control and increased harvest. Regulation schedules on multiple-purpose reservoirs are not subject to drastic changes for fishery purposes. However, such regulation in accordance with a seasonal pattern or rule curve may be a natural management tool. Furthermore, minor seasonal modifications in the normal plan of regulation are sometimes possible, if the operating agency is aware of a possible benefit. Over 200,000 pounds of rough fish were removed from Nimrod Reservoir in Arkansas after the waters were drawn down considerably below the conservation pool level to facilitate their capture (Hulsey, 1956). The Corps of Engineers varied its operation of Wister Reservoir, Oklahoma, on several occasions so that state personnel might collect fish from the large populations in the stilling basin below the dam (Hall and Latta, 1952). Unexpected opportunities for research and management occur at various times on all reservoirs. The Corps of Engineers has no control of the weather, and abnormal water levels during floods or droughts offer opportunities for executing control, sampling, or harvest measures that may not be possible with the water levels at the normal elevation.

Fishery personnel are urged to become familiar with the various phases of the operation and regulation of individual reservoirs with which they are concerned so that they might plan acceptable and effective management programs. In addition, they are urged to keep District Engineers and reservoir managers adequately informed of fish management needs with respect to reservoir operation, so as to facilitate cooperative action when the opportunity for desirable modification exists.

In conclusion, more than 84 million persons, a large percentage of whom were fishermen, visited Corps of Engineers' reservoirs and locks and dams throughout this country for recreational purposes in 1957. Over 57 million, or 68 percent, of the total visitations were recorded at projects in the 13 states of this Southern Division of the American Fisheries Society. Of that total, 76 percent occurred at projects in the four states of Texas, Oklahoma, Arkansas, and Tennessee. Those visitation figures offer considerable evidence that the operation of warm-water reservoirs for statutory purposes also produces considerable fishery benefits, even though they are obtained incidental to primary regulation for other purposes.

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